DIALING IN LETTUCE FERTILITY:

A GROWER'S NUTRIENT MANAGEMENT AND DIAGNOSTIC GUIDE

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INTRODUCTION

Fertility management can be challenging for many crops. There are multiple phases and variables that complicate fertility management, monitoring, and delivery. Fertility can have both a visual impact such as foliar symptomology and result in a decrease in overall plant growth. For lettuce (*Lactuca sativa*) visual aesthetics are key to the crops market value. The focus of this guide is to provide an overview of macronutrient and micronutrient fertility rates, nutrient disorders, and their symptoms to help growers diagnose fertility problems. The foliar tissue concentrations ranges presented in the text are from Veazie et al. (2024)This guide provides insight from research conducted at North Carolina State University focused on plant nutrition of lettuce.

Unit Conversions

$1\ mg \cdot L^{-1} = 1\ ppm$

$1\ mg \cdot kg^{-1} = 1\ ppm$

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MACRONUTRIENT FERTILITY RATES AND DISORDERS

This chapter highlights macronutrient deficiencies.

- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)
- Calcium (Ca)
- Magnesium (Mg)
- Sulfur (S)

Nitrogen (N)

Nutrient Disorder:

Nitrogen deficiency symptoms for ‘Salanova Green’ begins as an overall stunting with a pale green coloration. As symptoms progressed, the lower leaves became yellow and chlorotic. Nitrogen deficiency symptoms were similar for ‘Salanova Red’, however, initially plants appeared to have a darker red coloration when compared to plants that received adequate N fertility.

Similar Problems:

Sulfur deficiency can also exhibit overall yellowing of the foliage; however, sulfur deficiency will first appear on the mid section of the plant while nitrogen deficiency will first be observed on the lower foliage. Foliar tissue analysis can be used to assist in determining which element is causing visual symptoms.

‘Salanova Red’

‘Salanova Green’

Nitrogen (N)

Nitrogen Deficiency

‘Salanova Red’

‘Salanova Green’

Nitrogen (N) Fertility Rate

Fertility Rate:

After eight weeks of plant growth, a linear relationship between N fertility rate and plant dry weight was observed. Additionally, plants that received the highest examined N fertility rate of 150 mg·L^{-1} N exhibited the greatest plant biomass after eight weeks of growth.

However, N foliar concentrations did not increase when additional N was supplied beyond 111.4 mg·L^{-1} N after eight weeks of growth. While a plateau of foliar N concentration was observed at 111.4 mg·L^{-1} N , plant dry weight continued to increase up to the maximum examined N fertility rate of 150 ppm N. Growers should also be aware of the type of N they are applying. Nitrogen is plant available in a variety of forms the two most common are Nitrate (NO_3^-) and ammonium (NH_4^+). The ratio of nitrate or ammoniacal nitrogen included in a fertilizer will impact if a fertilizer is considered basic, neutral, or acidic. Ammoniacal-N is associated as being acidic and can lower substrate and hydroponic solution if growers are not careful. However, basic fertilizers contain a higher percentage of NO3- compared to acidic fertilizers.

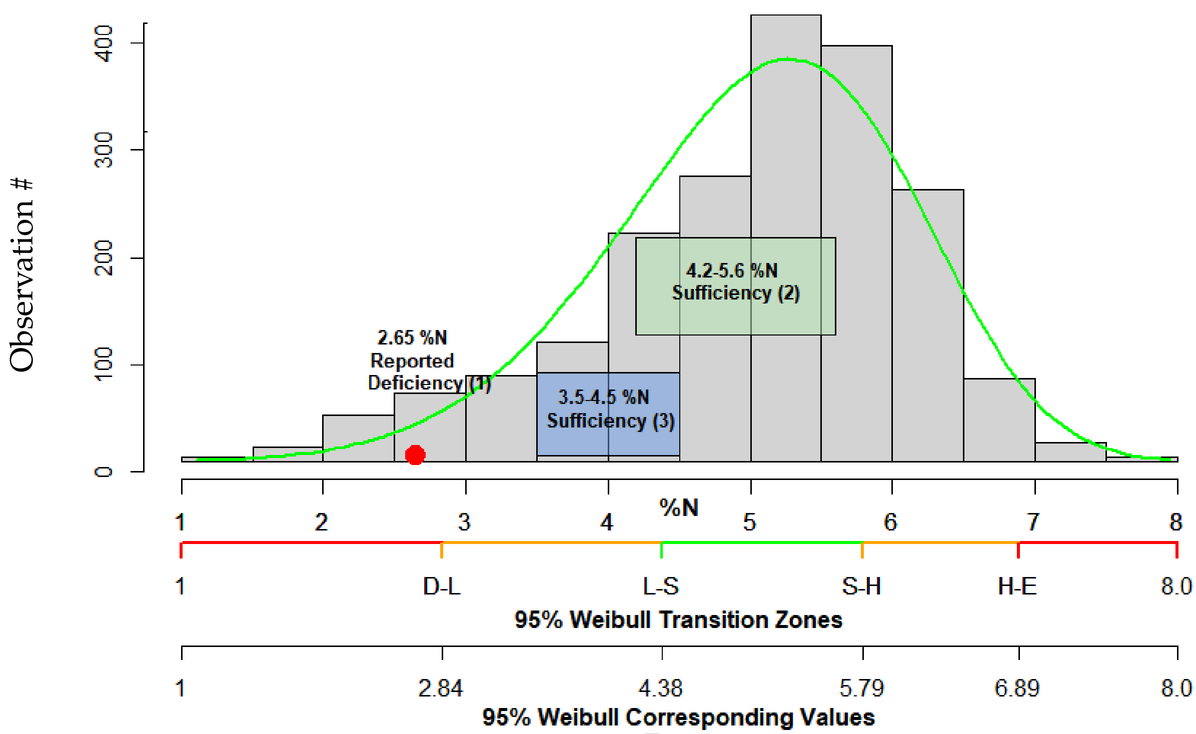
Nitrogen Foliar Tissue Concentration

Foliar Tissue Concentration Ranges:

While N toxicity is rare, ammonium (NH_4^+) toxicity can occur when excessive NH_4^+ concentrations are supplied or growing conditions for conversion of NH_4^+ to nitrate (NO_3^-) are suboptimal due to cold (<20°C) or excessive (>40°C) temperatures, waterlogged substrates, or with low pH (<5.6) conditions (Handreck and Black, 2002). While there are no foliar N toxicity concentrations reported for lettuce, the concerns are that unwarranted luxury uptake creates undue fertilizer waste as well as the potential for induced antagonisms with other essential nutrients. For instance, high foliar N concentrations are associated with lower boron (B), copper (Cu), and potassium (K) foliar concentrations (Marschner, 1995). Given the negative environmental and economic consequences of applying excessive fertilizers, the 6.89% N boundary value between High and Excessive established by this study seems more ecologically sound.

Nitrogen Foliar Tissue Concentration (%)				
Deficient	Low	Sufficient	High	Excessive
<2.84	2.84-4.38	4.38- 5.79	5.79-6.89	>6.89

Nitrogen Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Phosphorus (P)

Nutrient Disorder:

Phosphorus deficient plants exhibited severe stunting, yellowing of the lower leaves, and a dark, dull green coloration of the upper leaves. This darker coloration corresponds with the dark red coloration observed in P-deficient ‘Salanova Red’ plants.

Phosphorus deficiency symptoms were observed when plants exhibited a foliar P concentration of 0.09 to 0.17% at weeks six and eight, respectively. The onset of P deficiency symptoms is quick, with plants grown without P exhibiting symptoms within three weeks.

Similar Problems:

Nitrogen deficiency plants can also exhibit stunted growth; however, nitrogen deficient plants will exhibit a chlorosis that spreads upward into the middle leaves as the deficiency progresses.

‘Salanova Red’

‘Salanova Green’

Phosphorus (P) Fertility Rate

Fertility Rate:

At weeks three, six, and eight, plateaus for leaf tissue concentration were observed at 5.47, 14.76, and 9.86 mg·L^{-1} P, respectively.

Maximizing harvest weight is the goal of lettuce production. The largest dry weight occurred with a P fertility rate of 15.15 mg·L^{-1} P (34.71 mg·L^{-1} P_2O_5). This will enable growers to maximize yield and provide adequate leaf tissue P concentrations for 'Salanova Green'.

'Salanova Green' lettuce Phosphorus Rate

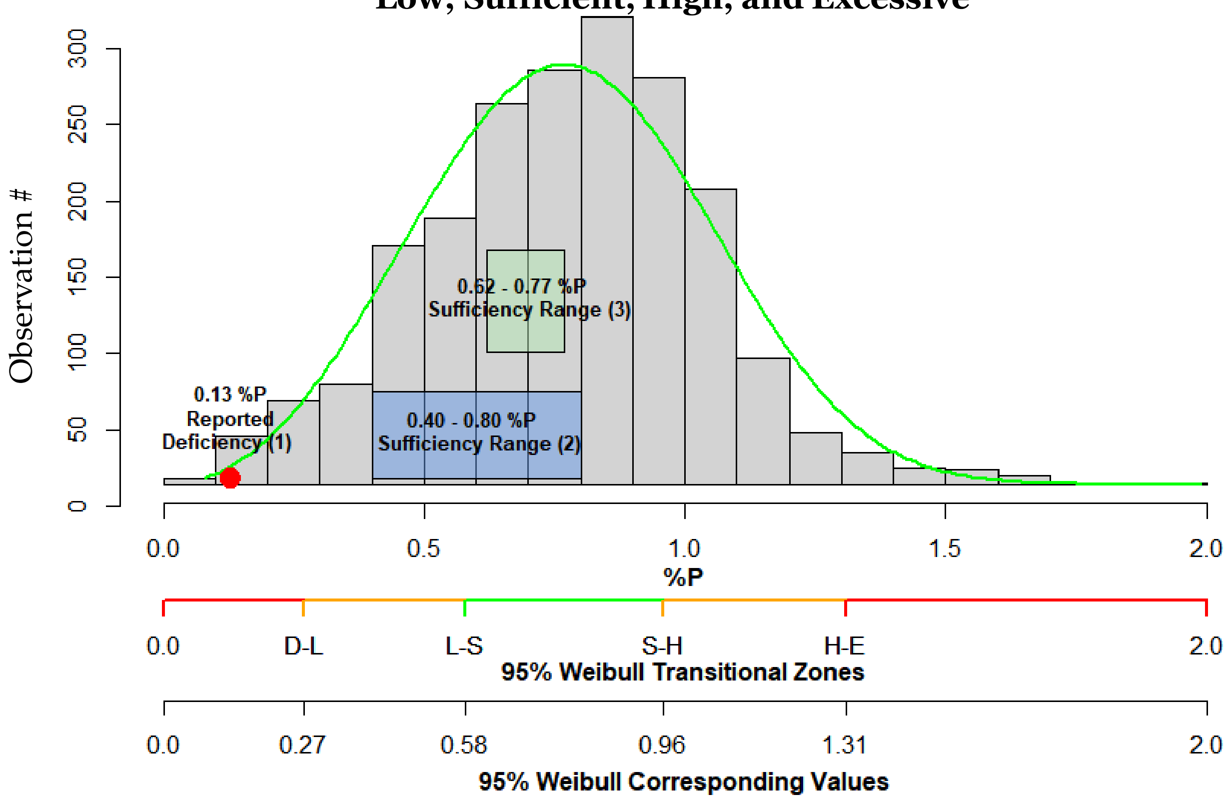
Phosphorus Foliar Tissue Concentration

Foliar Tissue Concentration Ranges:

A revised P sufficiency range of 0.58-0.96% P would provide growers with optimal growth without promoting luxury consumption. While P toxicity is not likely to occur, when P tissue concentrations get too high Fe deficiency can occur. Growers should avoid a P foliar concentration greater than 1.31% P to prevent nutrient antagonisms from occurring. Additionally, a P critical deficiency value of 0.27% P encompasses the previously reported critical deficiency value of 0.13% P reported by Henry et al., (2018).

Phosphorus Foliar Tissue Concentration (%)				
Deficient	Low	Sufficient	High	Excessive
<0.27	0.27-0.58	0.58-0.96	0.96-1.31	>1.31

Phosphorus Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Potassium (K)

Nutrient Disorder:

Potassium deficient plants were significantly affected when compared to plants that received adequate K fertility. Initially, K deficient plants exhibited stunting, leaf distortion, and marginal necrosis of the lower leaves. Marginal necrosis also occurred in response to K deficiency on ‘Salanova Red’ plants. Additionally, a visual decrease in red pigment was observed for ‘Salanova Red’ plants that were exhibiting K deficiency symptoms.

At week three, plants that received a K fertility rate of 0.0 mg·L^{-1} K had a foliar K concentration of 1.41% K, which is greater than the initial K deficiency foliar concentration of 0.79% K reported by Henry et al., (2018). This is likely due to the dilution effect since the plants in this experiment were sampled earlier than those by Henry et al. At weeks six and eight, deficiency symptoms were observed on plants with foliar K concentrations ranging from 0.39 to 1.03 % K.

Similar Problems:

Magnesium deficiency also exhibits chlorosis of the lower leaves; however, magnesium deficiency often exhibits more distinct interveinal chlorosis compared to potassium deficiency. Foliar tissue analysis should be used to confirm which element is problematic.

‘Salanova Red’

‘Salanova Green’

Potassium (K)

Fertility Rate:

At weeks three, six, and eight a plateau was observed at rates of 74.67, 68.57, and 50.07 mg·L^{-1} K, respectively, and provided optimal plant growth.

Plant dry weight did not increase when additional K fertility beyond 141.33 mg·L^{-1} K at six weeks of growth. However, plant dry weight increased linearly regarding increasing K fertility up to 150 mg·L^{-1} K at eight weeks of growth. Growers should be cognitive of luxury consumption occurring where the plant will continue to uptake K, but it is not essential for plant growth.

Potassium can be delivered in a variety of forms, most commonly potassium nitrate (KNO3) and potassium phosphate (KHPO4-). As a result, increasing your K fertility can impact other elements. Growers should monitor what salts are used in their fertilizer solutions to make sure that salts will not precipitate out of solution.

‘Salanova Green’ lettuce Potassium Rate

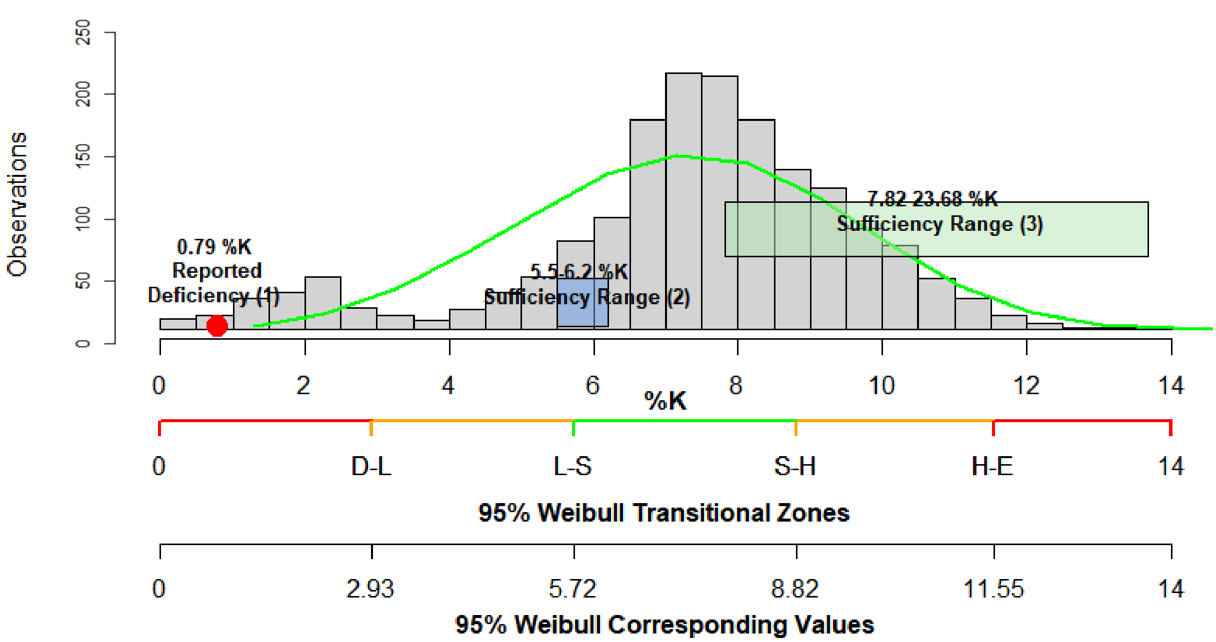
Potassium Foliar Tissue Concentration

Foliar Tissue Concentration Ranges:

A recommended K sufficiency range of 5.72-8.82% K narrows the previously reported range by Bryson et al.(2014). A more conservative deficiency critical value of 2.93% K encompasses the previous critical value reported by Henry et al. (2018) which was based on when first visual deficiencies were observed. Additionally, this distribution established an excessive critical value of 11.55% K that growers should avoid to prevent nutrient antagonism. While K toxicity has not been reported high K foliar concentrations can result in limited uptake of magnesium (Mg) and calcium (Ca).

Potassium Foliar Tissue Concentration (%)				
Deficient	Low	Sufficient	High	Excessive
<2.93	2.93-5.72	5.72-8.82	8.82-11.55	>11.55

Potassium Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Calcium (Ca)

Nutrient Disorder:

Calcium deficiency was initially expressed as severely stunted plant growth and wrinkled appearance on the upper foliage. As symptoms progressed, leaf margins curled down, and necrosis developed along the leaf margin. Additionally, in advanced stages, Ca-deficient leaves were thicker when compared to plants that received adequate Ca fertility. Symptoms were similar across ‘Salanova Red’ and ‘Salanova Green’.

Similar Problems:

Boron (B) deficient plants can also exhibit distorted foliage; however, B deficiency will often make leaves feel thicker compared to calcium deficient leaves. Growers should utilize foliar tissue analysis to confirm which element is deficient.

‘Salanova Green’

‘Salanova Red’

Calcium (Ca)

Fertility Rate:

At weeks three, six, and eight, quadratic plateau models best represented the relationship between Ca fertility and plant dry weight. At these three intervals, a plateau of 68.91, 36.11, and 29.90 mg·L^{-1} Ca, respectively, were observed. Additionally, when examining the relationship between foliar Ca concentration and Ca fertility rate, a quadratic plateau model exhibited the best fit at weeks three and six. At weeks three and six a plateau was observed at 23.34 and 50.28 mg·L^{-1} Ca. However, at week eight the linear quadradic model exhibited the best fit. For growers who are wanting to maximize biomass production a fertility rate of 68.91 mg·L^{-1} Ca allows for optimal biomass production while still providing adequate Ca foliar concentrations.

Higher Ca rates are often provided to lettuce with the utilization of a $CaNO_3$ fertilizer source and the desire to avoid tip burn. When plants are exposed to abiotic stress, one of the most common nutrient deficiencies in lettuce is tip burn as a result of localized Ca deficiency. Additional research is needed to determine if this lower rate of 68.91 mg·L^{-1} Ca is achievable for lettuce under abiotic stress conditions.

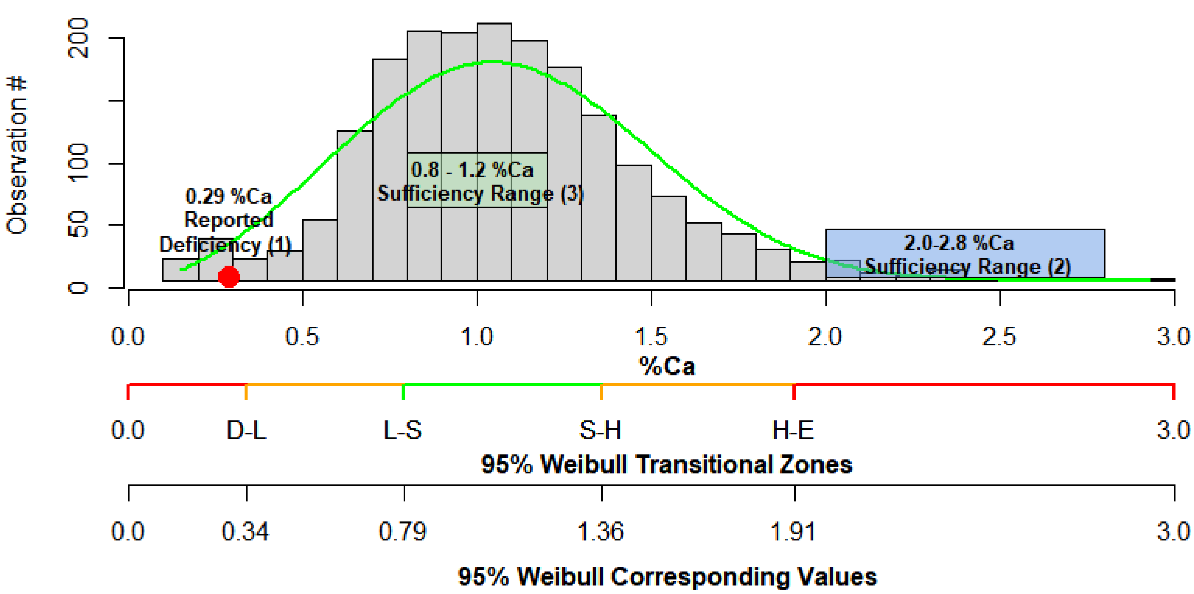
Calcium Foliar Tissue Concentration

Foliar Tissue Concentration Ranges:

A recommended sufficiency range of 0.79-1.36% Ca would expand the current Ca sufficiency range of 0.8-1.2% Ca reported by Bryson et al. (2014) and 0.88-2.0% Ca by Roorda van Eysinga and Smilde (1981) and would lower Ca sufficiency range of 2.0-2.8% Ca reported by Jones (2005). The Ca deficiency foliar concentration of 0.34% Ca based on the lowest 2.5% of the population was greater than 0.29% Ca reported by Henry et al. (2018) which confirms that this suggested deficiency range encompasses the previously reported deficient values. Currently, there are no published values for excess Ca or Ca toxicity in lettuce. However, when abundant Ca is supplied, luxury consumption of Ca can occur and may be reflected in the higher recommended range of 2.0-2.8% Ca reported by Jones (2005). This luxury consumption should be monitored for the possibility of interference with P, K, Mg, Fe, B, manganese (Mn), and Zn uptake (Marschner, 1995). Additionally, this provides the first excessive critical value for protected environment lettuce at 1.91% Ca.

Calcium Foliar Tissue Concentration (%)				
Deficient	Low	Sufficient	High	Excessive
<0.34	0.34-0.79	0.79-1.36	1.36-1.91	>1.91

Calcium Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



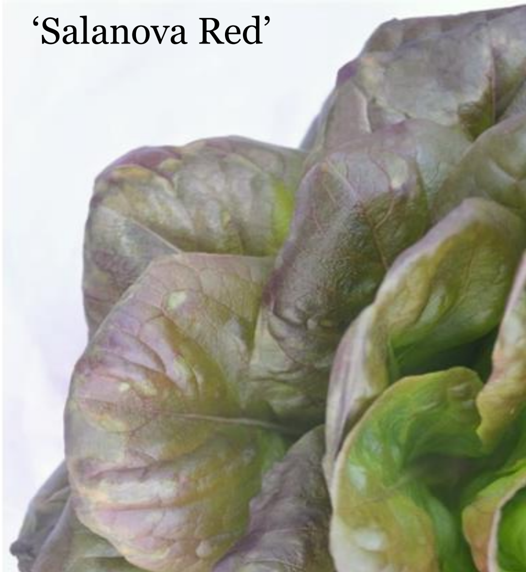
Magnesium (Mg)

Nutrient Disorder:

Magnesium deficient plants initially exhibited a prominent interveinal chlorosis on the lower foliage. As symptoms progressed, plants developed large necrotic spots along the lower leaf margins and between the veins. These symptoms were similar to the mottled necrosis along the lower leaf margins observed with ‘Salanova Red’ plants.

Similar Problems:

Potassium deficiency will exhibit similar interveinal chlorosis compared to Mg deficiency; however, K-deficient plants will exhibit necrosis quicker than Mg-deficient plants. Growers should confirm nutrient deficiency with foliar tissue analysis before applying corrective measures.



Magnesium (Mg)

Fertility Rate:

At week three, Mg fertility rate did not impact plant dry weight. At weeks six and eight, the relationship between Mg fertility rate and plant dry weight was optimized with Mg fertility rate of 22.08 and 11.73 mg·L^{-1} Mg. However, when examining the relationship between Mg fertility rate and Mg foliar concentration at weeks three and eight Mg peaked at 33.18 mg·L^{-1} Mg. This would suggest that for growers aiming to maximize plant biomass, a Mg fertility rate of 22.08 mg·L^{-1} Mg will allow for optimal biomass production while still providing the plant with adequate foliar Mg concentrations.

A supplemental application of Epsom Salts for growers with low alkalinity that are not using a cal-mag fertilizer can be used to supply supplemental magnesium.

Magnesium Foliar Tissue Concentration

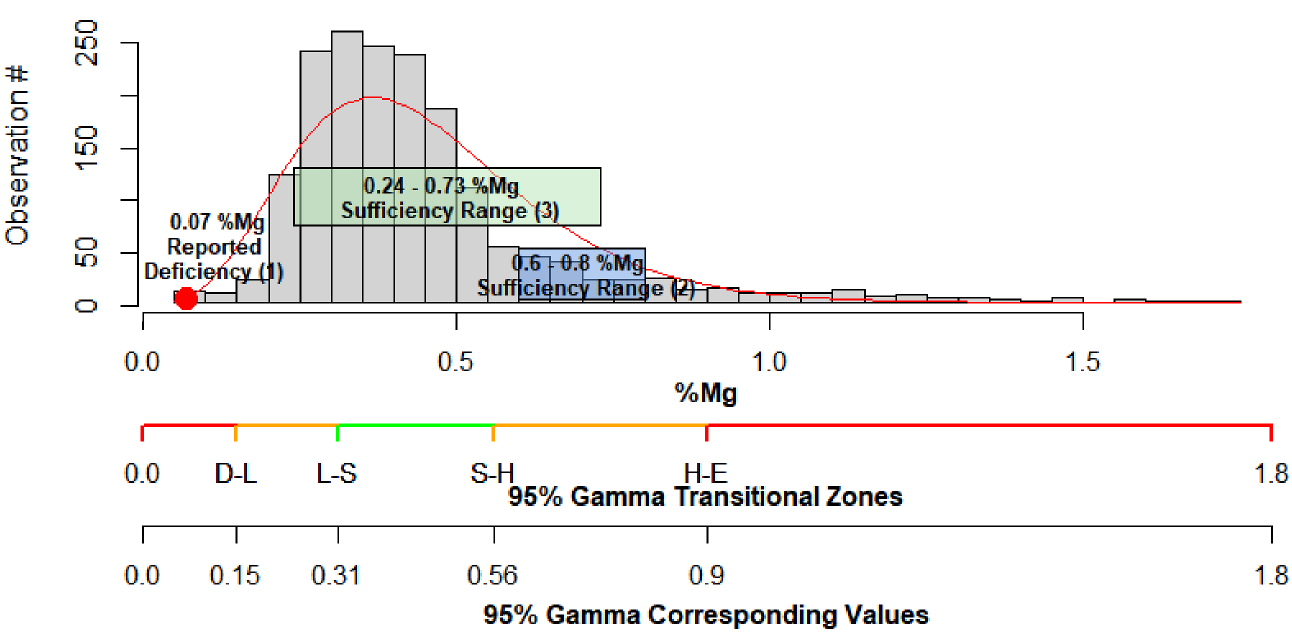
Foliar Tissue Concentration Ranges:

A recommended sufficiency range of 0.31-0.56% Mg is lower than the current recommendation of 0.6-0.8% Mg reported by Jones (2005) and 0.36-0.90% Mg listed by Roorda van Eysinga and Smilde (1981) and is also narrower than the recommended sufficiency range of 0.24-0.73% reported by Bryson et al., (2014). A deficiency critical value of 0.15% Mg encompasses deficiency values of 0.07 and 0.10%, reported by Henry et al. (2018) and Veazie et al. (2022), respectively.

Excess Mg in leaf tissue can inhibit photosynthesis and plant growth (Rao et al., 1987). Thus, Mg foliar concentrations must be closely monitored to promote optimal plant growth and avoid antagonisms with K and Ca uptake. This work establishes the first reported value of 0.90% Mg as being the critical value for excessive Mg foliar concentrations in lettuce.

Magnesium Foliar Tissue Concentration (%)				
Deficient	Low	Sufficient	High	Excessive
<0.15	0.15-0.31	0.31-0.56	0.56-0.90	>0.90

Magnesium Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Sulfur (S)

Nutrient Disorder:

Sulfur Deficiency symptoms developed rapidly for both cultivars studied. Plants initially exhibited severely stunted growth and a light green coloration throughout the entire plant. Symptoms were more pronounced on the upper foliage of the plant later in the production cycle.

Similar Problems:

Nitrogen deficiency will result in similar chlorosis as sulfur deficiency, but in the case of sulfur deficiency, chlorosis will begin in the middle foliage compared to nitrogen deficiency, where symptoms begin on the lower foliage. Plant stunting is also more pronounced with a N deficiency when compared to S deficiency.

‘Salanova Green’

‘Salanova Red’

Sulfur (S)

Fertility Rate:

While there was a limited visual impact of S deficiency, plant dry weight at all three sample points was impacted. At weeks three, six, and eight, a plateau of 20.29, 11.84, and 19.32 $mg \cdot L^{-1}$ S, respectively, provided optimal plant growth. When examining the interaction of S fertility and S foliar concentrations, a plateau was observed at 6.99 and 3.30 $mg \cdot L^{-1}$ S, respectively, at weeks six and eight. This would suggest for growers who are aiming to optimize plant biomass should target a fertility rate of 20.29 $mg \cdot L^{-1}$ S early in the production cycle.

This would suggest expanding the previously reported S deficiency foliar concentration of 0.09% S by Henry et al. (2018) to include 0.9 to 0.19% S. With limited variation in S leaf tissue concentrations coupled with similar dry weights, this would suggest that the recommended S fertility rate of 25.0 $mg \cdot L^{-1}$ S can be lowered to 20.29 $mg \cdot L^{-1}$ S.

Sulfur Foliar Tissue Concentration

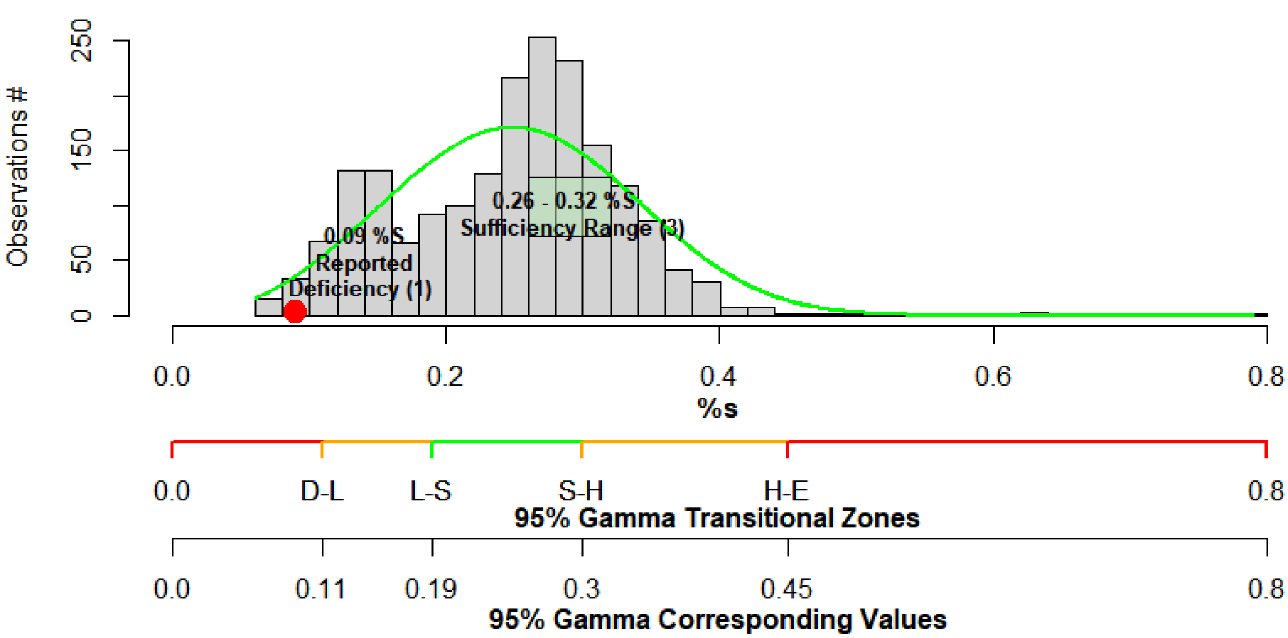
Foliar Tissue Concentration Ranges:

This study suggest a recommended sufficiency range of 0.19-0.30% S which is lower than previously reported. Additionally, a deficiency value of 0.10% S was similar to that reported by Henry et al. (2018) of 0.09% S confirming that <0.1% S is inclusive of previously reported deficiency values.

Currently, there are no reported excessive or toxic S foliar concentrations of lettuce, however, this work establishes 0.42% S as the critical value between High and Excessive levels and offers a target value that may need future refinement.

Sulfur Foliar Tissue Concentration (%)				
Deficient	Low	Sufficient	High	Excessive
<0.10	0.10-0.20	0.20-0.30	0.30-0.40	>0.40

Sulfur Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



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MICRONUTRIENT FERTILITY RATES AND DISORDERS

This chapter highlights micronutrient deficiencies.

- Iron (Fe)
- Manganese (Mn)
- Boron (B)
- Copper (Cu)
- Zinc (Zn)

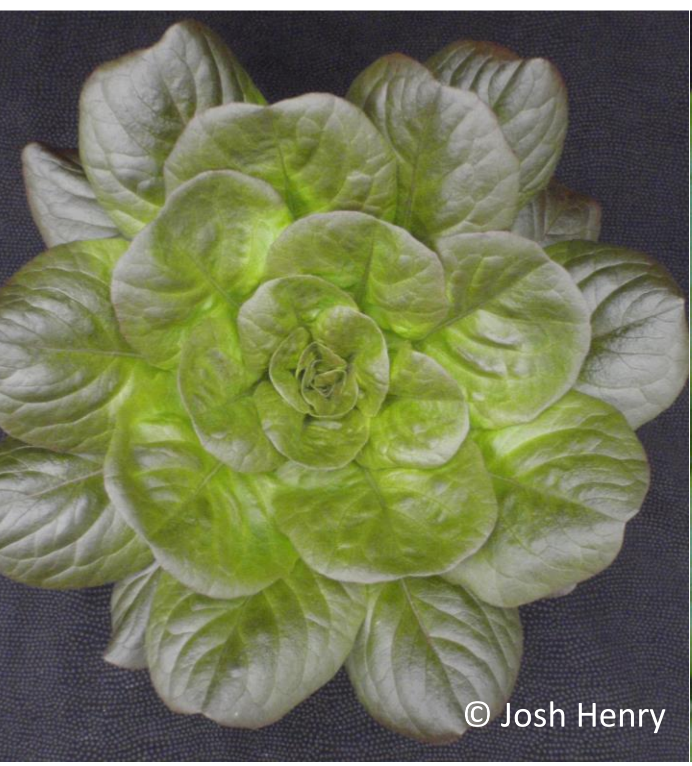
Iron (Fe)

Nutrient Disorder:

Iron deficient plants developed a moderate interveinal chlorosis on the upper foliage. Iron deficient plants were not significantly smaller than control plants that received Fe fertility for either cultivar. 'Salanova Green' had similar foliar Fe levels compared to the controls. These results were similar to what was observed with 'Salanova Red' lettuce, indicating that these two cultivars have a low Fe requirement and are tolerant of low Fe conditions. More evidence supporting this conclusion was that the foliar Fe levels found in control plants were less than half of the minimum value of the Fe sufficiency range of 168 to 223 $mg \cdot kg^{-1}$ reported by Bryson et al. (2014) for greenhouse grown butterhead lettuce.

Similar Problems:

Similar interveinal chlorosis symptoms as Mg will be observed; however, iron deficiency will appear first on the younger foliage compared to Mg which is initially observed on the lower foliage.



'Salanova Red'

'Salanova Green'

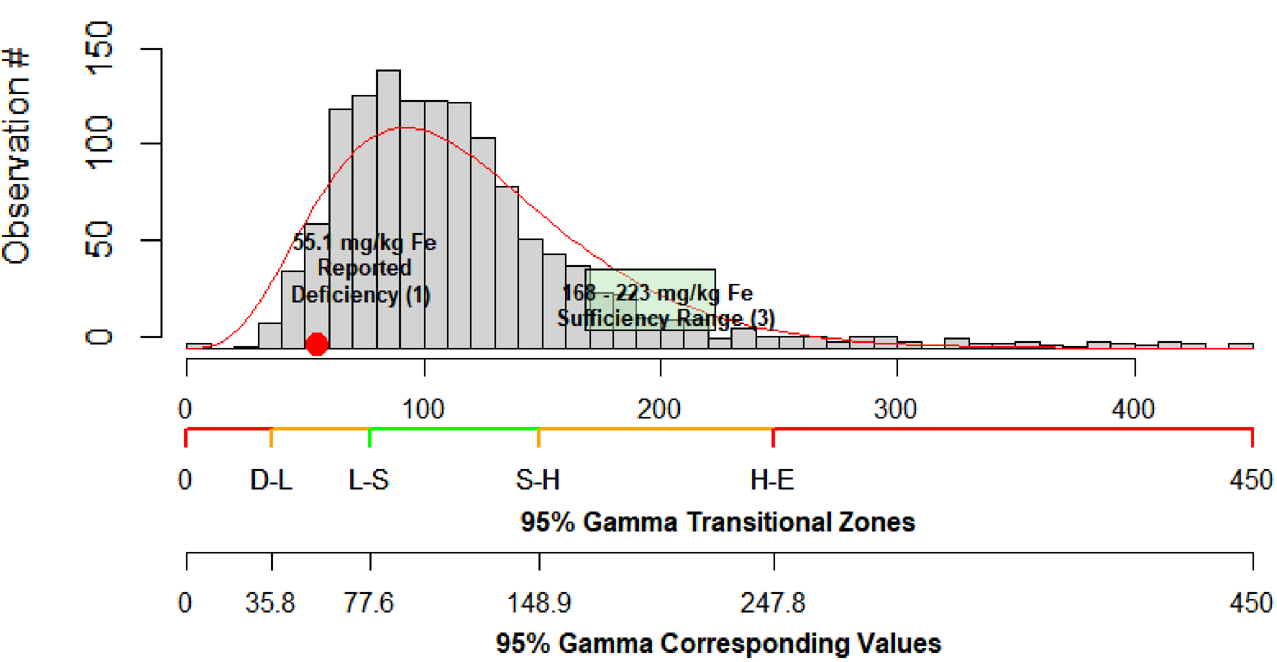
Iron Foliar Tissue Concentration

Foliar Tissue Concentration Ranges:

A recommended sufficiency range 77.6-148.9 mg·kg⁻¹ Fe would decrease the current Fe sufficiency range reported by Bryson et al. (2014) of 168.0-223.0 mg·kg⁻¹ Fe. The Fe deficiency foliar concentration of 35.8 mg·kg⁻¹ Fe was less than 55.1 mg·kg⁻¹ Fe reported by Henry et al. (2018). Currently, the reported approximate toxic Fe foliar concentration of lettuce is set at >500 mg·kg⁻¹ Fe (Jones, 2005). Roorda van Eysinga and Smilde (1981) healthy range of 55.9-558.5 mg·kg⁻¹ Fe encompasses the entire spectrum recommended in this study from deficient to excessive, but they also stated that Fe values varied widely and most likely limited their ability to classify leaf Fe concentrations. Additionally, Salanova varieties appeared to be more tolerant of low Fe, further refinement of this data is needed to be cultivar specific. This research provides the critical value between high and excessive by recommending that the excessive transitional zone begin at 247.8 mg·kg⁻¹ Fe.

Iron Foliar Tissue Concentration (mg·kg⁻¹)				
Deficient	Low	Sufficient	High	Excessive
<35.8	35.8-77.6	77.6-148.9	148.9-247.8	>247.8

Iron Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Manganese (Mn)

Nutrient Disorder:

Manganese deficient plants developed an overall bright green coloration in the young foliage and appear stunted compared to healthy plants. In other species, interveinal chlorosis and a pale netted appearance that develops into white spots will occur in advanced stages. Manganese deficient plants were 24.5% smaller than control plants and exhibited tissue concentrations of 7.49 $mg \cdot kg^{-1}$ Mn compared to 85.34 $mg \cdot kg^{-1}$ Mn in healthy plants (Henry et al., 2018).

Similar Problems:

Similar interveinal chlorosis symptoms as those associated with Fe deficiency are typically observed. Light pale discoloration similar to S deficiency can also occur but will primarily be focused on the upper foliage.

‘Salanova Red’ ‘Salanova Green’

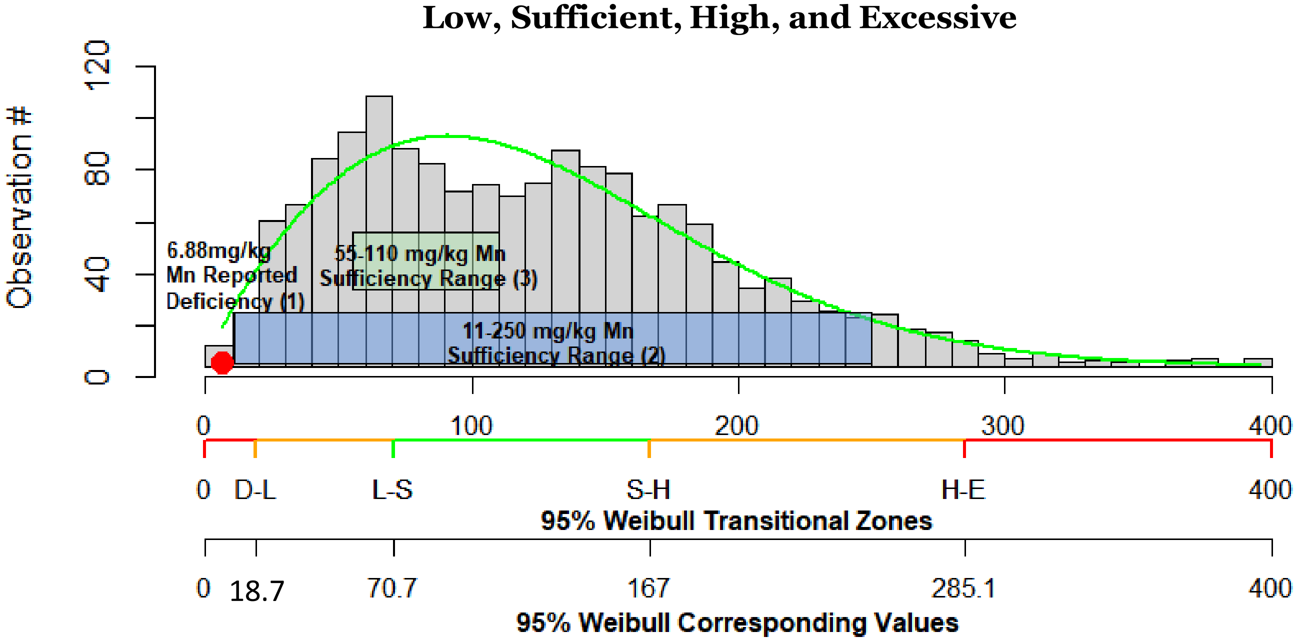
Manganese Foliar Tissue Concentration

Foliar Tissue Concentration Ranges:

A recommended sufficiency range of 70.7-167.0 mg·kg^{-1} Mn expands the current Mn sufficiency range of 55-110 mg·kg^{-1} Mn (Bryson et al., 2014) and narrows the Mn sufficiency range of 11-250 mg·kg^{-1} Mn reported by Jones (2005) or 30.3-197.8 mg·kg^{-1} Mn recommended by Roorda van Eysinga and Smilde (1981). These previous recommended ranges were much wider due to the limited sample quantity utilized in the recommendation. By using much larger sample populations more accurate and narrow sufficiency ranges can be provided. Additionally, a deficiency critical value of 18.7 mg·kg^{-1} Mn is lower than the <22.0 mg·kg^{-1} Mn by Roorda van Eysinga and Smilde (1981) yet encompasses the previously reported value of 6.88 mg·kg^{-1} Mn by Henry et al. (2018). Reuter and Robinson (1997) reported toxic Mn foliar concentration for lettuce to be approximately 333 mg·kg^{-1} Mn or more. A wider range was reported by Roorda van Eysinga and Smilde (1981) who considered >198 or 302 mg·kg^{-1} Mn to be toxic. This research decreases the critical value between high and excessive zones to >285.1 mg·kg^{-1} Mn.

Manganese Foliar Tissue Concentration (mg·kg^{-1})				
Deficient	Low	Sufficient	High	Excessive
<18.7	18.7-70.7	70.7-167.0	167.0-258.1	>258.1

Manganese Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Boron (B)

Nutrient Disorder:

Boron deficient plants exhibited distortion and thickening of the upper younger foliage on both cultivars studied by Henry et al. (2018). 'Salanova Red' plants exhibited lesions of raised gall-like protrusions (Henry et al., 2018). Boron deficiency was observed with B foliar concentration of 7.7 mg·kg^{-1} (Henry et al., 2018).

Similar Problems:

Calcium deficiency exhibits similar tip burn and leaf distortion; however, B deficient plants exhibit thicker foliage compared to Ca deficient plants. Growers should utilize foliar tissue analysis to confirm the specific nutrient deficiency.

'Salanova Red'   'Salanova Green'

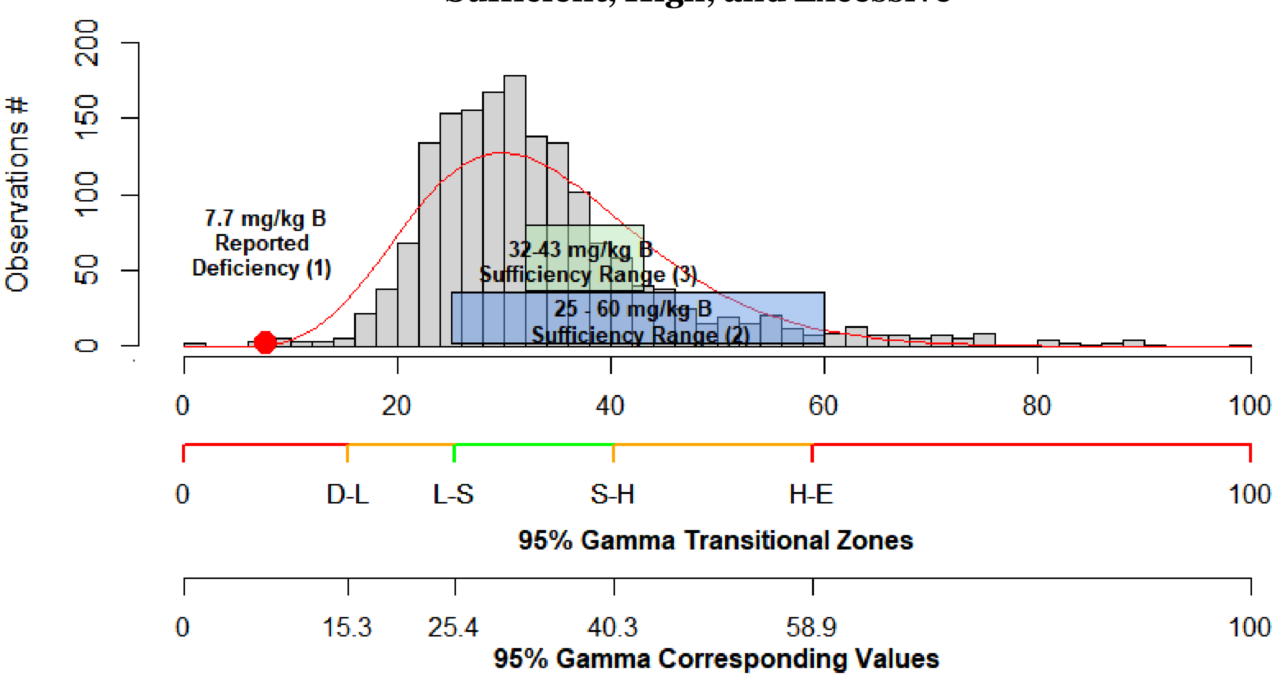
Boron Foliar Tissue Concentration

Foliar Tissue Concentration Ranges:

A recommended sufficiency range of 25.4-40.3 mg·kg⁻¹ B narrows the current recommendation of 25-60 mg·kg⁻¹ reported by Jones (2005) and 21.6-64.9 mg·kg⁻¹ B listed by Roorda van Eysinga and Smilde (1981) and also lowers the recommended sufficiency range of 32-43 mg·kg⁻¹ reported by Bryson et al., (2014). A deficiency critical value of less than 15.3 mg·kg⁻¹ B encompasses deficiency values of 7.7 mg·kg⁻¹ reported by Henry et al. (2018), yet Roorda van Eysinga and Smilde (1981) considered 21.6 mg·kg⁻¹ B to be deficient. Currently, the reported approximately excessive B foliar critical values of lettuce are concentrations >50-200 mg·kg⁻¹ B (Jones, 2005). Roorda van Eysinga and Smilde (1981) considered >54 or 65 mg·kg⁻¹ B to be toxic. This research increases the transition between high and excessive zones to >58.9 mg·kg⁻¹ B.

Boron Foliar Tissue Concentration (mg·kg⁻¹)				
Deficient	Low	Sufficient	High	Excessive
<15.3	15.3-25.4	25.4-40.3	40.3-58.9	>58.9

Boron Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Copper (Cu)

Nutrient Disorder:

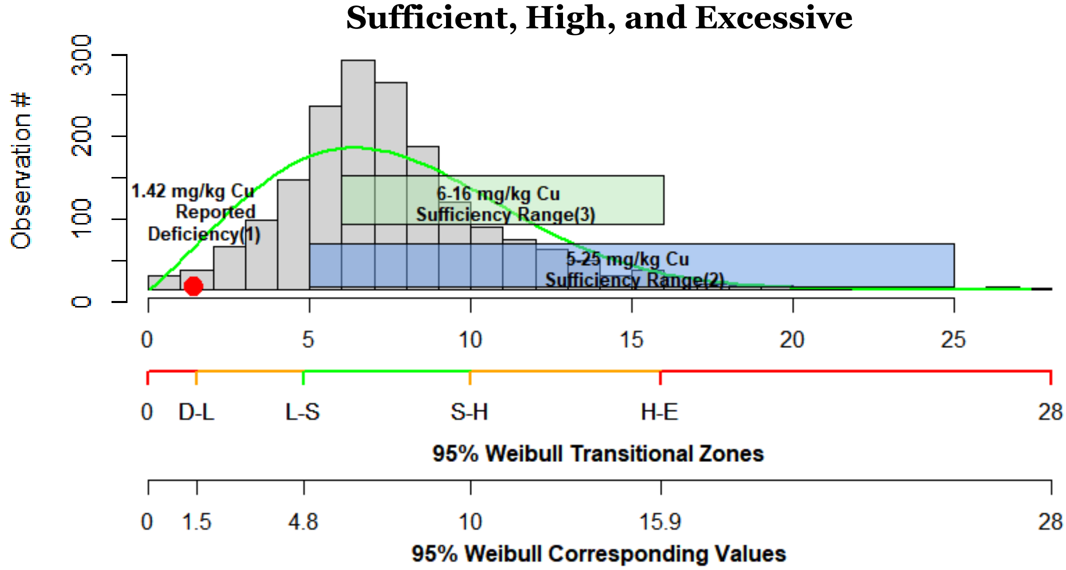
Copper deficiency symptoms were not observed after six weeks of growth without this element being present in the fertilizer solution. This indicates that Cu is unlikely to pose a significant risk of deficiency for hydroponic growers. After six weeks of growth 'Salanova Red' lettuce grown without Cu fertilization exhibited foliar tissue concentrations less than 1 mg·kg^{-1}. Similarly, 'Salanova Red' lettuce grown without Cu fertilization exhibited a foliar tissue concentration of 1.42 mg·kg^{-1} Cu after six weeks of growth.

Similar Problems:

Copper problems are very rare in hydroponic lettuce production. Growers should utilize foliar tissue analysis to confirm that Cu is deficient prior to corrective measures.

Copper Foliar Tissue Concentration (mg·kg^{-1})				
Deficient	Low	Sufficient	High	Excessive
<1.5	1.5-4.8	4.8-10.0	10.0-15.9	>15.9

Copper Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



Zinc (Zn)

Nutrient Disorder:

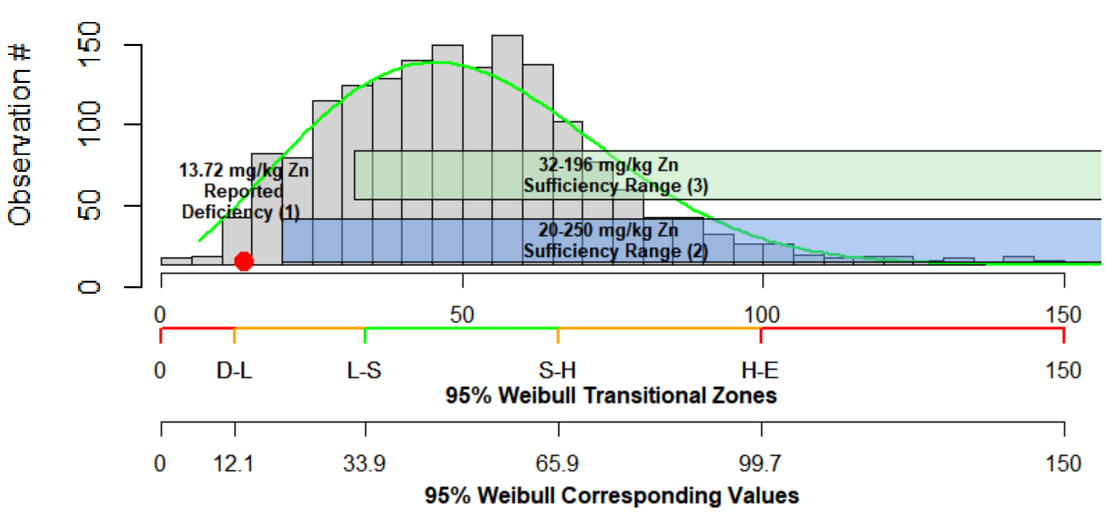
Zinc visual deficiency symptoms were not observed after six weeks of growth and likely do not pose a large risk of deficiency for hydroponic growers. After six weeks of growth 'Salanova Red' exhibited a Zn foliar tissue concentration of 15.28 mg·kg^{-1}. Similarly, 'Salanova Red' exhibited a foliar tissue concentration of 13.72 mg·kg^{-1} Zn when Zn fertility was withheld after six weeks.

Similar Problems:

Zinc problems are very rare in hydroponic lettuce production. Growers should utilize foliar tissue analysis to confirm that these nutrients are deficient prior to corrective measures.

Zinc Foliar Tissue Concentration (mg·kg^{-1})				
Deficient	Low	Sufficient	High	Excessive
<12.1	12.1-33.9	33.9-65.9	65.9-99.7	>99.7

Zinc Foliar Concentration in Lettuce Deficient, Low, Sufficient, High, and Excessive



4

NUTRIENT MONITORING

This chapter highlights nutrient monitoring options for growers

- Leaf Tissue Analysis
    - Routine Diagnostic
    - Diagnostic Analysis
- Petiole Sap Monitoring

Leaf Tissue Analysis:

Routine Analysis (Problem Prevention), allows growers to monitor nutrient uptake in the plant during production. This requires a grower to take multiple samples over the entire course of the growing season. This method allows growers to identify problems or issues before they become serious concerns.

Routine Analysis sampling is conducted as a general management tool when there are no negative symptoms on the plant. The strategy here is to determine the nutrient status of the plant to ensure your fertility program is on track by plotting tissue values over time.

This nutritional monitoring strategy requires that each cultivar be sampled individually, as nutrient levels may vary by cultivar. In addition, if there are differences in the plant's age or fertilization practices, those blocks of plants should be sampled separately as well.

The second method, **Diagnostic Analysis (Problem Solving)**, is used to diagnose deficient or toxic nutrients when the plants are displaying negative symptoms. This process is used when a problem is encountered to help identify the cause. This is primarily a corrective tool. Plant tissue analysis is especially useful in determining micronutrient levels in the plant and has a greater level of accuracy than a substrate test using a water-based extraction.

Plants being sampled for Diagnostic Analysis should be sampled individually. To accurately diagnose a nutritional disorder, a sample will need to be taken from the affected plant and/or symptomatic portion of the plant. For example, if the lower leaves are displaying toxicity symptoms, then those leaves should be sampled. Because the critical lower deficiency and toxic upper critical values for lettuce are being developed at this time, if possible, a "good" control sample should also be collected for comparison to your problem sample.

Leaf Tissue Analysis: Sampling Procedure

• The leaf tissue sample should be representative of the plant, or production area, being monitored, or the problem you wish to analyze. As mentioned above, plants of different age and variety should be sampled separately.

1. **Collecting Leaf Samples.**
   a. **Routine Analysis (Problem Prevention).** For routine analysis, the most recently mature leaf (MRLM) should be collected, which is typically 3 to 5 leaves down from the growing tip. For a representative sample, take a total of 25 to 30 leaves from 10 to 20 plants.
   b. **Diagnostic Analysis (Problem Solving).** Plants should be sampled individually with leaves being taken from the affected portion of the plant. If possible, sample a "good" control so that comparisons can be made.

2. If the crop has been overhead watered or micronutrients have been foliar applied, gently wash the leaves in distilled water for 20 seconds to remove any surface contaminants. Dry the leaves with paper towels after washing, prior to packaging them.

3. Samples should be sent in a paper bag or manila envelope to the commercial lab for analysis. Label the bag with your name and address. Additionally, label the samples as healthy or symptomatic if applicable.

4. Deliver the samples immediately to a lab certified to conduct leaf tissue analysis. Try to collect the sample at the beginning of the week so delivery will not be delayed over the weekend. If delivery time to the laboratory (or to a drying oven) is expected to exceed 12 hours, then it is best to refrigerate or air-dry the samples.

Petiole Sap Monitoring Sampling Procedure

Petiole sap monitoring allows growers to monitor and diagnose phloem mobile nutrients (N, K, and Ca). This method allows growers to monitor and diagnose fertility on site. This can be useful in fast maturing crops, such as lettuce, where it may take multiple days to receive foliar analysis results from a lab. This method of monitoring can be utilized for many crops. However, growers must establish a baseline of what an adequate petiole sap concentration is for each lettuce cultivar grown with a particular fertilization strategy.

Sampling Procedure:

1. The petiole sap sensor must be calibrated when utilized. This is accomplished by placing 3-5 ml of the calibration solution on the sensor. The sensor should then be rinsed with deionized (DI) water.

2. Once representative leaves have been selected the midrib should be removed from the rest of the leaf (Fig. 1). At this point, the foliage of the leaf excluding the midrib may be discarded.

3. Petiole sap will then be extracted utilizing a press (Fig. 2), the sap should be placed on the sensor and the user should close the lid and record the measurement displayed on the screen.

4. The petiole sap sensor should be rinsed with DI water between samples to ensure accuracy.

Figure 1. (Left) An example of separated midribs.
Figure 2. (Right) A press similar to a garlic press be utilized for petiole sap extraction.
Figure 3. (Below) Showing petiole sap on the sensor and the reading achieved.

Summary

Monitoring nutrient status of a fast-maturing crop, such as lettuce, is essential to producing optimal yield. There are many options to monitoring nutrient status of a crop cycle including leaf tissue analysis and petiole sap analysis. Leaf tissue analysis provides a more detailed insight as to the nutrient status of your lettuce crop. Tissue analysis results will help you determine if your fertilizer program is on target by providing current nutrient levels in the plant. In addition, tissue testing is one of the best methods for diagnosing nutrient disorders. Petiole sap monitoring can be completed quickly in-house and can assist growers in narrowing down the possible problems. However, petiole sap sufficiency ranges must be determined for each cultivar.

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